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THE EFFECTIVENESS OF LIGHTING—ITS NUMERICAL ASSESSMENT

(Contributions presented on Tuesday, February 9th, 1943.)

(I) BY METHODS BASED ON SUBJECTIVE BRIGHTNESS MEASUREMENTS

by W. D. WRIGHT *(Member)*

The effectiveness of a lighting system may have to be judged by tests of actual performance of the particular task for which the lighting is provided, owing to the complexity of the task and the number of variables involved. In many cases, any separate investigation of each of the variables would present too elaborate an analysis to lead to any useful evaluation of the merits of the system. Nevertheless, tests of actual performance may not always be easy, and it would be a great advantage if there were some simple visual criterion with which to judge at least a proportion of lighting systems. It is my purpose to examine how far subjective brightness can be used as this criterion.

Subjective brightness is the brightness of an object as it appears to the observer. It is, in fact, the magnitude of the visual sensation, which cannot be measured in the true sense of measurement but which, by comparison with a scale of photometric brightnesses seen under defined conditions of observation, can be numerically identified or specified. There is, however, some hope that this scale might, if properly chosen, possess the property that equal arithmetical intervals corresponded, at least approximately, to equal intervals of sensation or equal steps of contrast and would, in that case, be of wider scope than as a means merely of identifying or describing subjective brightness values.

Subjective brightness depends on a number of factors of which the following are the most important: (1) photometric brightness; (2) state of adaptation of the eye; (3) colour of the object; (4) contrast with neighbouring objects and background; (5) presence of glare sources; (6) area of the retina employed.

To appreciate the part played by each of these items, we may note the following facts:—

(1) Increase of photometric brightness increases the subjective brightness.

(2) When the eye is dark adapted, a given photometric brightness has a greater subjective brightness than when the eye is light adapted.

(3) As the intensity is reduced, colours from the red end of the spectrum acquire a relatively lower subjective brightness compared with greens and blues, owing to the Purkinje effect.

(4) Objects seen against a dark surround have a higher subjective brightness than when seen against a light surround.

(5) Glare sources reduce the subjective brightness through contrast and inhibitory action, but the light scattered in the media of the eye may also add a component.

(6) Owing to the varying light sensitivity across the retina, objects viewed at the fovea have a relatively higher subjective brightness than when viewed in the extra-fovea, provided the intensity is high and the eye is light adapted; at low intensities and when dark adapted, the subjective brightness is greater in the extra-fovea.

Subjective brightness matters because it describes directly the visual impressions we receive. Further, visibility is governed by the contrast between object and surround or between parts of an object, and this in turn is determined by the relative magnitude of the subjective brightness of different parts of the field. We cannot assume that in all cases an increase in subjective brightness or a greater contrast is necessarily desirable, hence the employment of subjective brightness as a criterion of good seeing may in some cases involve subsidiary information relating subjective brightness with the performance of the eye in other respects, e.g., low subjective

brightness means poor visibility, very high subjective brightness means glare.

The particular merits of subjective brightness observations are that they record what we actually see, and do not relate to some idealised or limiting conditions. It would be foolish to suggest that they provide a criterion of universal application, but the following examples illustrate their scope:—

(1) Record of dark adaptation process. The increase in the subjective brightness of an object with increasing duration of dark adaptation may be instructive in connection with installations in which the illumination is appreciably above the threshold. For example, it might be found that only a comparatively short period of dark adaptation was required to secure maximum visual sensitivity.

(2) In systems using red illumination, the outer parts of the field appear relatively dark owing to the preponderance of rods in the peripheral areas of the retina. This darkening might be conveniently described in terms of subjective brightness.

(3) When an object is seen in a low illumination, its visibility increases as its area increases. The advantage resulting from a large area might usefully be recorded by the gain in subjective brightness, and it might be found that the optimum area for supra-threshold illumination was different from that found by tests on thresholds. If so, which result should be used?

(4) The specification of a glare source might be given in terms of its subjective brightness or, if area has to be included, in terms of its subjective intensity. Measurements could be made to determine the level at which the subjective brightness or subjective intensity reached an intolerably high level, and glare limits could be expressed in terms of such a level. It might reasonably be claimed that this would be the fundamental method for the specification of glare since it automatically takes into account the effect of state of adaptation, area of retina, etc., which is not the case when glare is specified in terms of candle-power or candles per unit area. Thus if the glare present in two radically different types of lighting system had to be compared, the subjective brightness of the sources in one system when seen by a person working under that system would be compared with the subjective brightness of the other sources when seen in their proper setting in their own system.

(5) The merits of a street lighting system could be evaluated in terms of its revealing power of an object against a background by recording the difference between the subjective brightness of the object and background.

(6) In interior lighting the merits of a system are in part, possibly in large part, determined by the impression the lighting makes when a person first enters a room. Good taste in lighting, as with good taste in dress, demands that the lighting should not draw attention to itself but should fit in with its surroundings to such an extent that the observer should be hardly conscious of the method or means by which a room is lit. If a person, on first entering a room, receives a first impression either of gloominess or gaudiness, then the lighting is defective, despite the fact that after a few minutes in either room he may become adapted to the illumination and no longer be conscious of these attributes. The impressions he receives are largely a function of subjective brightness values, which ought to be determined for a given building; that is to say, if a person is likely to go from a reading room to a lecture hall, or from a dining room to a concert hall, the lighting system should be designed to avoid excessive changes in subjective brightness levels. Again, a room lit by purely indirect lighting appears to have a more sombre appearance than when the sources themselves are visible, for the same level of illumination. This may mean that the subjective brightness values are different in the two cases; if so, some numerical data on the matter would be of interest. As a further illustration of the importance of subjective brightness in relation to ordinary indoor lighting installations, I find that if, in my dining room, I switch on one 60-watt lamp in a fitting suspended

from the middle of the ceiling, the illumination is gloomy and unimpressive; if I switch on a second 60-watt lamp, the illumination is greatly improved and quite acceptable. I have the impression that the illumination is improved out of all proportion to the increased amount of light provided. This may be pure imagination, but there ought to be some means of evaluating the magnitude of these visual impressions. It might turn out to be of no little sales value to know the ideal subjective brightness under various conditions.

(7) In lighting for advertising purposes, the striking character of an advertisement is closely related to the subjective brightness of the advertisement and its background.

(8) In aesthetic lighting, e.g., architectural lighting as in churches, or the floodlighting of exteriors, the success of the installation depends in part on the proper balance and grading between the subjective brightness of the various parts of the building. An investigation of the relation between artistic lighting and subjective brightness and subjective colour should bring out matters of considerable interest.

(9) In industrial lighting, the hard shadows and glaring surfaces frequently in evidence are disadvantages, because their subjective brightness is too low or too high. Their limits should properly be expressed in terms of subjective brightness.

I would claim that many lighting problems are inherently problems of subjective brightness and that the only reason the illuminating engineer has not been more concerned with the matter is that subjective brightness is difficult to measure. At the moment it is obvious that this is a serious handicap to the numerical assessment of lighting values by this means, and I have personally no further suggestions to offer than those reported in 1941.* It is remarkable that we have made no use of any system by which to describe just how bright or how dark an object appears to be, although there are examples which show that the illuminating engineer has, on occasion, to make allowance for the change in subjective brightness with change in observing conditions. Thus, the B.S.I. specification for fluorescent and phosphorescent paint (A.R.P. 18) and for standards of low brightness (A.R.P. 52) take account of the Purkinje effect, which is one of the factors affecting subjective brightness; while in the specification of lighting systems a limit is sometimes laid down either to the intensity or the brightness of a source to avoid glare, the limiting value increasing with the angle between the source and the object of central interest in the room, e.g., the blackboard in a schoolroom. The increase in the limit with angle is in part due to the decrease in light sensitivity of the peripheral retina, again a factor governing subject brightness of which the illuminating engineer, wittingly or unwittingly, makes use.

We may hope and expect that the illuminating engineer will become more "subjective brightness conscious" in the future, but I see no reason why he should not also attempt quantitative observations. One day we may see glare specified in "brills," just as noise is specified on "phons."

* W. D. Wright. Trans. I.E.S. **6**, 23, 1941.

(II) BY METHODS BASED ON VISUAL ACUITY

by K. J. W. CRAIK
(Psychological Laboratory, Cambridge)

Visual performance is affected by a number of factors (apart from the observer's own visual standard). The chief are: illumination on the working surface, reflection factor of the material worked upon, glaze on this surface, distribution of the light as affecting reflection from material and glare, and periodical changes in illumination (or necessary movements of the eyes producing the same effect). Visual performance can be judged from a number of fundamental properties of vision, the chief being differential brightness sensitivity, visual acuity, absolute sensitivity (at very low illuminations), critical flicker frequency, speed of reading, visual reaction time, and subjective brightness.

The problem is whether we can relate these sets of factors to one another so as to be able to predict the visual performance to be expected

from a lighting set-up, or design the lighting system to give a certain performance. The problem arises from two quite different origins—first, that foot-candles alone are not a complete indicator of the visual performance to be expected; a well diffused and a glaring system may give different performance for the same power consumption; and, secondly, that different visual tasks demand different intensities of lighting; it is foolish expenditure of power to light a railway station to the same level as an operating theatre. I think it would be unwise to attack one of these problems without the other; the lighting system must be suited to the particular kind of task to be done. The I.E.S. code and American work have gone quite a long way in specifying illumination levels and suitable lighting systems for a number of different tasks. It ought to be possible to work out some such list expressed in terms of a "visual efficiency" scale. Thus it would be said that watch-repairing, engraving, and operating required 100 per cent. visual efficiency, reading ordinary print 50 per cent., heavy manual work 25 per cent., walking without hitting obstacles 5 per cent., and so forth; the actual figures I have quoted are purely arbitrary and will be discussed later.* The illuminating engineer would then know what visual efficiency was required in a particular situation and could decide how to secure it. A good installation would be one which gave this efficiency for the least expenditure of power; a bad installation would be, typically, one in which naked lamps close to the line of sight made the visual performance equal to that of an installation with lower wattage consumption. Owing to the number of different factors affecting visual performance, and the number of different tasks, I do not myself think it will be possible to find any unit of measurement, whether subjective or objective, which will supplant the foot-candle; but I think it might be possible, while keeping the foot-candle as the basic measurement, to have a visual efficiency scale which acts both as a tentative "correction factor" upon it, so as to indicate how many foot-candles are needed for the task in hand, and to show whether a certain installation gives a good performance for its wattage. I am not sure whether this visual efficiency scale should take the form of an empirical correction table, in the light of which the foot-candle readings are judged, or whether one should attempt to produce an instrument which would read visual efficiencies directly. The trouble is that the effect merely of change of illumination, other things being the same, is different upon the different visual functions. Reading rate, for print of a constant size, does not obey the same laws as acuity or brightness discrimination. When we come to the effect of glare sources the position is still worse. A glare source may have a marked objective effect on the absolute threshold near it, but an immeasurably small effect on visual acuity measured against the working surface brightness; again, the physical effect of glare on the threshold is the same for concentrated filament and for an opal bulb illuminating the eye equally, but the discomfort is greater with the former, and Luckiesh and Moss find greater constriction of the pupil and disturbance of natural blinking rate in that case. Whether or not glare will be produced also depends on the task. A shielded concentrated source near the work may be admirable for working on dark cloth, but produces glare by specular reflection if used for machine-tools or instrument assembly. There are also great personal variations in susceptibility to glare.

Let us take the particular case of acuity. Visual acuity can be measured close to a glare source, as has been done by Sweet, Depene, Nowakowski, Cobb, Lythgoe, and others, but it is not measurably reduced by intense glare unless the background used for the acuity test-object is very dim. I made an instrument in which a rotating frame held two phosphor bronze strips, so that their separation and apparent width decreased, as the frame was

* After making the above suggestions I had the advantage of reading Mr. Weston's suggestions for a new code, in which visual efficiency is used in a different sense, as relative to the best performance of the task.

rotated, until they were not resolved. With this it was not possible to show any decrease in acuity when the background against which this test object was seen was itself illuminated by the glare lamp and was at ordinary reading or working distance from the observer (e.g., 1 to 3 ft.). To obtain any measurable effect one had to screen the background from the direct illumination of the glare source or place a neutral filter between the background and the instrument. This does, of course, represent a fairly common situation, for glare is most troublesome when we are trying to see into a dark corner of a room or box, or a dark hole in a machine near a powerful light, and we are entitled to imitate the worst working conditions. But what background brightness are we to use for the test wires, to represent fairly the visual situation and the additional psychological discomfort? I think it is clear that one cannot use a fixed background-brightness, for a glare source which rendered the wires completely invisible in artificial lighting might be completely innocuous by day, and conversely the wires would never be visible in the surrounding glare of the brightest daylight—the best illuminant of all—if the background was dim enough to make them useful as glare-indicators at night. So a filter which reduced the background brightness of the actual working surface by a certain fraction was tried with a little more success, but the reduction had to be so great, to show measurable glare effects, that one was really using acuity as a rather ineffectual way of measuring brightness discrimination; and as brightness discrimination is known to be more affected by glare the lower the illumination, an absolute threshold test was devised in which the amount of light admitted through an instrument from the working background was varied until it was just visible against a totally dark surround inside the instrument. This was much more successful, though it admittedly represents a rather artificial situation, and the exact scale one is to engrave on it remains a matter of doubt. Here we may return again to visual acuity. Although it is an insensitive indicator of glare, it is one of the fundamental properties of vision and is of the utmost importance in reading, engraving, fine instrument work, sewing, etc. Data on its changes under different illuminations and lighting conditions should therefore be taken into account in the setting up of any table of visual efficiencies or the calibration of any visual efficiency meter, though it should not, I think, be weighted more than some other visual functions. That, perhaps, is where visual acuity enters in the assessment of lighting conditions—as one factor among several, but one whose relation to the others is not so completely established that it can be left out in favour of some more sensitive indicator, such as photometric brightness or change of threshold. Visual acuity is affected by various other things (such as the colour of the light used, vibration of the test object, and the transition from cone to rod-stimulating levels of illumination). These conditions do not necessarily affect the other visual functions in quite the same way, so visual acuity should be given some weight in drawing up the visual efficiency scale.

Finally, if such a scale of visual efficiency were used, either as a correction table or as an instrument-reading, what type of scale should it be? Various scales could be made, such as scales (if they are legitimate) of subjective brightness; but when made I do not think they have any immediate meaning to the ordinary person or to the illuminating engineer. The *size* of the object to be worked upon is the basic determinant of the illumination required and so, though visual acuity is a poor indicator of glare, its dependence on background brightness may be a good basis for a visual efficiency scale. One might, therefore, suggest that visual efficiency should be defined as the reciprocal of the angular width of a black (or possibly grey) dot which is just visible on a background of a certain brightness, the size of dot which is just seen by a person with 6/6 vision against a background of 500 or more e.f.c. being taken as 100 per cent. The angular width of a black dot which is just visible varies over a 100:1 range between the highest background brightnesses and a brightness of approximately 0.00005 e.f.c., which is very convenient; such a scale

of efficiencies from 1 per cent. to 100 per cent. would therefore cover a brightness range from a rather dark night illumination with no moon or artificial light up to summer daylight. Artificial light of 1 to 50 ft.c. would be of the order of 60 per cent. to 80 per cent. efficiency. An instrument measuring absolute threshold, as described above, would be susceptible of calibration in such terms, and would automatically weight the scale with a glare-factor; if visual efficiencies were used to form a correction-table a weighted glare factor would have to be introduced.

The visual efficiency meters described were developed with a grant from the Medical Research Council.

(III) BY METHODS BASED ON BLINKING RATES

by SHEILA J. MACPHERSON
(Psychological Laboratory, Cambridge)

The ease of doing visual tasks depends on other things besides the illumination—for instance on the avoidance of glare, shadows, and bright reflections from the material worked upon. Stiles, Holladay, and others have shown that a glare source decreases the visibility of dimly illuminated objects near them; but this effect depends only on the illumination falling on the eye from the glare source. But it is known from everyday experience that a naked filament lamp is a more unpleasant source of glare than one in an opal bulb or diffusing shade. Can one measure, in any objective way, this difference between the lights of the two kinds? Luckiesh and Moss have suggested three possible methods—blinking rate, pupil dilatation, and the unconscious pressure of one's finger on a button. If any of these methods were satisfactory it would be a useful measure of the difficulty or ease of doing a job which can be done reasonably well, in contrast to visual measurements which record a threshold of some kind—i.e., the illumination or distance at which the object can just be seen.

Luckiesh and Moss claim "that the rate of blinking is increased without exception when the *specific* visual task is made more difficult or more prolonged," though they admit that *different* visual tasks cannot be thus compared, as some give abnormally low initial blink rates. Repetition of their experiments on reading under glare conditions supports their finding that the blink rate increases progressively. The percentage increase in blink rate was smaller, however, e.g., about 15 per cent. instead of about 50 per cent. as found by Luckiesh and Moss, though the glare illumination was greater, and the glare angle the same, in the present experiments.

Luckiesh and Moss appear to pay insufficient attention to the low initial blink rates which may be caused by

(1) over-anxiety and concentration on a task; and

(2) tasks whose performance would be impaired by rapid blinking.

This, to some extent, contradicts Luckiesh and Moss's findings quoted above, since counting turns of fine wire, for example, may be impaired by rapid blinking causing one to lose one's place. Such suppression of blinks may alternate with spasms of rapid blinking in the intervals of work. These variations in blink rate make increase of rate an inaccurate measure of difficulty of seeing.

The present experiments are concerned with seeing small marks in connection with a war problem. The task is not intellectually difficult, but requires continuous concentration and has given rise to complaints of "eye-strain." It was thought that these might be partly due to reduction of the normal blinking rate, due to concentration on the job, which might result in drying of the surface of the eye and sensations of smarting. There were likely to be other factors such as getting too near the job, so that convergence and accommodation were strained, but blinking rate was thought worth investigation.

Dr. Craik made an automatic blink recorder, consisting of a spectacle frame with a light phosphor bronze wire attached to it; this was bent so as to rest in the groove on the subject's upper right lid. The subject did not feel it when it was rightly adjusted, and was told that the apparatus and adjustments were for a study of eye-movements, to avoid making

him self-conscious about his blinking. The lower end of the wire dipped in a small insulated mercury-pot on the spectacle frame and made electrical contact when the subject blinked; this operated an electric counter. When properly adjusted the instrument was independent of direction of gaze in the horizontal plane and independent of angle of sight in the vertical place between about 10° above the horizontal and 30° below. This instrument could be used in complete darkness; but owing to the delay and care required in adjusting it some of the present measurements were made with a hand counter; the subject was watched from the side, slightly behind, and eye-blinks counted without attracting attention.

Apart from looking for the small mark mentioned above, the tests used were plotting curves from tables, reading print in low illuminations, looking for aircraft silhouettes on a dimly lighted screen, and counting a row of identical dots, made by rolling a knurled wheen on carbon paper placed on white paper. Blink rate was somewhat reduced in all cases, as compared with the normal rate of the subject when unoccupied; the last test gave the greatest reduction. In it, if the subject blinked, he risked losing his place in the dots, and he was therefore anxious not to blink if possible. When the test was finished, or even during the course of it, the subject might find himself forced to blink, and quite a volley of blinks was necessary to restore the normal rate. Thus the smarting sensation seems to linger on and is not corrected by a single blink. Although other workers have shown that the blink reflex is not entirely caused by drying of the conjunctiva, and is set off by some nervous rhythm even if the surface of the eye is anaesthetised, it seems certain that, when sensation is intact, drying or possibly cooling of the eye does stimulate blinking. For instance, a blast from an electric hair-dryer causes spasms of blinking.

The variations in blink rate in different individuals are large and the effects of the visual tests irregular, but on the average blink rates were reduced by the following amounts:—

Counting rows of dots: 58 per cent
Picking up aircraft silhouettes: 52 per cent.
Plotting graphs: 21 per cent.
Reading at 20 ft.c.: 37 per cent.
Reading at 0.25-0.5 ft.c.: 42 per cent.

It was also found that when the eye looks upward a greater surface is exposed; this appears to be the cause of an increase in blinking rate found under such conditions. It seems advisable, therefore, to arrange instruments, books, etc., so that the observer is looking down rather than up, since reduction in the normal blinking rate will have a more serious effect when he is looking upwards. The relative areas of eye surface exposed at different angles of regard with the head vertical throughout are:—

Mean of two subjects:

Angle above horizontal.	Height of opening.
30°	1.15 cm.
20°	1.05 cm.
10°	0.90 cm.
0°	0.85 cm.
Angle below horizontal.	**Height of opening.**
10°	0.75 cm.
20°	0.67 cm.
30°	0.60 cm.
40°	0.45 cm.
50°	0.35 cm.
60°	0.20 cm.

This represents two or three times the amount of vertical eye-movement without head movement which would be encountered in practice, but the effect even then is quite large.

To sum up, blink rate is an irregular thing, often reduced by the specific task, even though during the performance of that task it may increase progressively, or be compensated by spasms of blinking, and it is very unlikely that it could be used, in practice, as an indicator of good or bad lighting conditions.

This work is being conducted with a grant from the Medical Research Council.

(IV) BY METHODS BASED ON VISUAL THRESHOLDS

by W. S. STILES *(Fellow)*
(National Physical Laboratory)

Several attempts have been made to use visual thresholds as a basis in assessing the effectiveness of lighting, and I shall refer to one or two of these

later. My main purpose is to give a brief general outline of the principles —and difficulties—which apply to all such attempts.

In any determination of a visual threshold a few essential elements enter. The subject is called upon to perform a visual task, usually a simple one, such as detecting an object or reading a Snellen letter under controlled conditions. One of the physical variables determining the conditions—for example, the size or brightness of the object—is changed, so that for some values the subject succeeds, for others, fails in the task. The limiting value separating success from failure is the threshold. This notion of a threshold is extremely wide. When the task is to detect the presence of an object, and when the conditions are changed by altering the difference of brightness between the object and its background, the resulting threshold is known as the brightness difference threshold, with which we are particularly concerned in visibility problems. Figure 1 gives the results of a

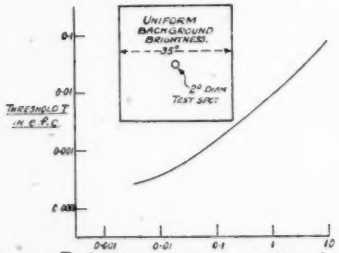


FIG. 1. BACKGROUND BRIGHTNESS B IN c.f.c.

series of measurements of the brightness difference threshold T for an object of angular diameter 2°, seen at the centre of a large uniform background of brightness B.

If we wished to assess the effectiveness of lighting in a practical situation in which the activity in hand was the detection of a 2° object at the centre of a uniform background, we could do so at once with the aid of the threshold curve of Fig. 1. The lighting will determine the background brightness B, and hence the brightness difference threshold T, and it will also determine the difference of brightness $\triangle$ between the object and its background. The lighting is effective only if $\triangle$ exceeds T. An immediate objection to this procedure is that it admits only two degrees of effectiveness—effective and ineffective. The difficulty is acute, because the threshold values of Fig. 1 are very low—T is only a few per cent. of B—and although we cannot deny that the eye can see such small differences, we know they are inadequate in everyday life.

In some practical situations $\triangle$ may be necessarily proportional to B, e.g., when object and background form parts of the same surface, and then changing the lighting comes to increasing or reducing the illumination. The above criterion leads to a particular level of illumination, above which lighting is effective, and below which it is ineffective. In other cases, however, notably in street lighting, the brightness of object and background can be varied independently, and there is scope for lighting designers to obtain the requisite value of $\triangle/T$ by suitable choice and layout of the light sources.

It has been implied that the lighting can affect the threshold T only by determining the background brightness B. In fact, the lighting affects T in other ways. At very low levels of illumination there are differences in the threshold values for lights of different colours, although for commercial illuminants these differences are small. At all levels the threshold for a given background brightness may be raised by the presence of unshielded light sources in the field of view. Again, it has been shown [Cobb, Craik] that the threshold is raised if the field surrounding the immediate background is either too bright or too dim. The effects on T have been measured in several laboratory investigations and have been applied in assessing effectiveness.

Returning to the difficulty just mentioned, it is, of course, realised that the threshold is not a sharp limit. When the conditions are near threshold the subject does not always succeed or always fail in the allotted task in successive trials under constant conditions. The sharp transition must be replaced by a curve showing

the probability of success for different values of the variable condition. A mean curve of this kind obtained in measurements of the brightness difference threshold is shown in Fig. 2. The chance p of seeing the test object in a single trial is plotted against the difference of brightness △ between the object and the background (△ on a logarithmic scale). Within a certain range of values of △ the chance p increases regularly as △ increases; above this range there is practical certainty of seeing, and below it practical certainty of missing, the test object. The actual extent of the range in question will depend on the precise conditions of observation, as well as on the value of p, which is accepted as "practical certainty." There may also be considerable individual variations. The value of △, for which p equals 0.5, is usually taken as the actual threshold value, and with this convention it seems that in laboratory measurements little, if any, increase in certainty of seeing is to be obtained by making △ more than about twice the threshold value. It is a step forward to use the chance p as the measure of effectiveness, but the gap between brightness difference thresholds determined in the laboratory and the differences of brightness required in practice is not bridged.

Test object: Size	2°	0.1°	0.1°	0.4°
Test object: Exposure ...	Continuous	0.75	0.75	0.05 sec.
Test object: Direction of view	Direct	Direct	5° indirect	5° indirect
Threshold as percentage of background brightness	1%	8%	25%	11%

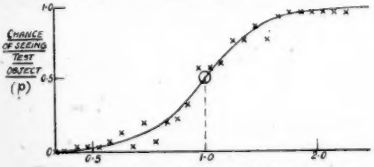


FIG. 2. BRIGHTNESS DIFFERENCE △ IN UNITS SO CHOSEN THAT THE THRESHOLD VALUE T EQUALS 1·0.

The commen-sense explanation of this gap is that, in practical seeing, conditions are more difficult than those usually employed in the laboratory. First, there are the more obvious differences. Practical seeing frequently depends on vision of small detail; we need to become aware of objects at which we are not actually looking, and we wish to see things "at a glance." Laboratory conditions can be made more difficult in these respects, and when this is done the thresholds approach more nearly the values which seem to be operative in practice. The following results, which all refer to a background brightness of one e.f.c., illustrate this point:—

When an "object" is presented on a uniform background, anything seen must be the object sought. This simplification rarely applies in practical situations, where an object has often to be seen and recognised when it forms part of a pattern containing a great deal of detail in which the observer has no interest. The possible effect of the *meaning* of a contrast pattern on its chance of being seen is raised here. In disruptive camouflage, invisibility is brought about, not by reducing the differences of brightness exhibited by the object, but, in fact, by adding new contrasts which so modify the contrast pattern that it ceases to have meaning. The attempt to assess the visibility of, say, a zebra in its natural surroundings, by dividing the difference of brightness of its stripes by an appropriate brightness difference threshold would be futile. With meaning may be classed the mental attitude and distribution of attention of the observer, all of which help to determine the effective visibility of objects. These psychological factors cannot be kept out of the discussion. It will probably be agreed that the trend of modern street lighting is to present to the motor driver an unbroken sheet of uniform brightness, produced by semi-specularly reflected light from the road surface, on which any object will stand out as an

isolated black silhouette. The aim has been to obtain a high difference of brightness between object and background for all object positions. At the same time, however, the conditions are psychologically very favourable; any break in the uniformity signs itself at once as something of which the driver must take note. It had earlier been urged that a streaky background was desirable to ensure that some part at least of an object should present an adequate difference of brightness with the background. Lighting on these lines would be psychologically unfavourable.

The threshold method has developed from its simple form on two main lines. On the one hand, the visual task is made a more and more exact copy of the activity which it is intended to carry out in the lighting installation. In the end, the threshold measurement entails an investigation, like that of Weston and Taylor on type-setting, in which the speed and accuracy of work under different conditions of lighting are determined in an actual installation, with the "observers" going about their business as they normally would. From the results of an investigation of this kind it may be possible to say that, for a prescribed speed and accuracy of work, the illumination must not fall below a certain value $E_\circ$, that no exposed light source must come within an angle $\theta_\circ$ of the working material, and so on. Once the required speed and accuracy are specified, it can be decided whether any proposed lighting is effective by seeing whether the illumination exceeds $E_\circ$, the sources lie outside the angle $\theta_\circ$, and so on. $E_\circ$ and $\theta_\circ$ etc., may be regarded as the effective threshold values. Studies of industrial lighting on these lines are difficult to organise, and the information obtained is not easily carried over to processes which are not closely similar to that actually investigated. An interesting attack on this last mentioned difficulty has been made by Beuttell and Weston, but the full results are not yet available. In exterior lighting, speed of traffic and accident rate are the counterparts of speed and accuracy of work, but it is almost impossible to use them as indicators of effectiveness of lighting.

The application of the threshold method to exterior lighting has followed a different line. The aim has been to construct a picture—a numerical picture—of the effectiveness of lighting by showing how well objects can be seen in different parts of the installation. I shall mention two investigations, one an attempt by Dunbar and myself to assess the relative merits of different headlight beams, the other an evaluation of revealing power in street lighting by Waldram. In the headlight case, we considered two cars approaching, each equipped with headlights of a given type. We calculated for different positions of the cars and of a standard test object, the brightness difference $\triangle$ between object and background, as seen by the driver of one car and the corresponding brightness difference threshold T, allowing for the glare from the headlights of the other car. An array of thirty-six values of the ratio $\triangle/T$ was obtained, indicating the visibility conditions during the passing of the cars. The threshold values used were based on laboratory determinations. To allow for the greater difficulty of practical conditions, the ratio $\triangle/T$ was required to exceed five before the object was accepted as visible. If this occurred for x out of the thirty-six values of $\triangle/T$, x could be regarded as a crude figure of merit for the particular headlight beam examined. In this way symmetrical, flat-topped and "dip and swivel" beams were compared, the last of these coming out best.

In the street lighting case Waldram considered the values of $\triangle/T$ for all objects between the eye of the observer and a given point of the road surface, allowing for the different reflection factors of outdoor garments (F. C. Smith's measurements). For the threshold values, he used a curve determined by Dunbar under actual street lighting conditions. The observers were required to drive along a uniformly lit street and had to decide by successive trials, when, in their opinion, the difference of brightness between the road surface and a standard test object placed on the road was sufficient to permit safe driving at 30 m.p.h. By allotting a score of 1 if $\triangle/T$ exceeded unity, and

0 otherwise, Waldram derived for each point of the background a mean score (or probability value), the array of all these mean scores, giving a picture of the revealing power of the lighting installation. A single figure of merit was also derived, but both Waldram, in the case of street lighting, and Stiles and Dunbar, in the case of headlights, emphasise that no single figure can fairly represent the merits of the installation.

At various stages in the above investigations, assumptions, explicit or implicit, are made about the relative importance of seeing objects in different positions. Such assumptions cannot be avoided if it is wished to sum up the whole merits of an installation. They do not arise in the simpler problem of assessing the visibility of a single object. Something should be said of visibility meters which attempt to make such an assessment in an actual installation. The glare-meter [Stiles and Crawford], and Bouma's visibility meter measure the threshold T at a given point of the background; thus they take account only of the denominator of the fraction $\triangle/T$, and in general auxiliary measurements of $\triangle$ are required if deductions about the effectiveness of lighting are to be drawn. Moreover, the T values obtained tend to be the laboratory rather than the effective values. In visibility meters employing an absorbing-diffusing wedge, the object is reduced to the threshold by interposing a certain amount of wedge between the eye and the object. It is implied, in effect, that by inserting the wedge, conditions of observation are made more difficult in the same way as in practical seeing, and that an object which requires more wedge before it disappears will remain visible longer in practice when we glance hastily, look out of the corner of the eye, and so on. Dunbar has demonstrated the weaknesses of meters of this type, although it is not of course denied that visibility meters can be usefully applied in some experiments.

I do not think that the threshold method will place in the hands of illuminating engineers instruments enabling them to assess effectiveness of lighting on the spot. Nor does it seem likely that calculations such as Waldram's for street lighting will be used to make routine derivations of the effectiveness of particular installations in the same way as we derive their cost. The value of this and similar analyses rests chiefly on the pointers given to the best ways of improving lighting. At the same time they may provide evidence on which specifications and lighting codes can be based. The results of studies of interior lighting serve a similar purpose. In the minimum illuminations, maximum source brightnesses, minimum mounting heights and so on, of the lighting codes the effective threshold values are seen in practical use.

DISCUSSION

The PRESIDENT said the authors had put forward some rather tantalising ideas and had not given the answers, but he hoped the discussion would do that. Perhaps the paper on eye blinks could be summarised by saying the author had satisfied everybody that blinking was no "blinking" use!

Dr. J. W. T. WALSH, after congratulating the authors, said he also congratulated the Society on facing up to a problem which had always been lurking in the background and occasionally pushed itself forward in a disconcerting way. Various methods had been devised for assessing the effectiveness of a lighting system, and although those who had been responsible for them had managed to convince themselves, he believed they had failed entirely to convince anybody else. One of these methods, sponsored by prominent members of the illuminating engineering industry in another country, had, he hoped, received its *coup de grâce* that evening, and he thanked Mrs. Macpherson for that.

In a way he had had a sense of relief in listening to these papers, because he had always had an uneasy feeling that to look for some method of evaluating the effectiveness of a lighting system was a search for the impossible. What was the effectiveness of a lighting system? Surely it was quite likely that an installation which would be highly effective for one job would be far from effective for another job. If he had a certain amount of money to spend on a camera, his choice from among a number of cameras with different characteristics would depend upon what he was hoping to do with his camera. This was a rough analogy with what they were trying to do with lighting systems. The lighting system for reading a book

or some similar task would be quite different in its main characteristics from the lighting system for such a task as darning a hole in a stocking; yet, taking the lighting necessary for the living room, the same installation had to be effective for both tasks.

In the case of lighting for various processes in factories, the job was often fairly well defined, but he still felt the object must be to measure the effectiveness of any lighting system for carrying out a particular job, and in no other way could a reliable answer be obtained. Therefore they were driven back to the method of trying things out under practical conditions. The effectiveness of a lighting system for a particular job would be a combination, in various proportions, of the different characteristics of lighting installations. Therefore, what should really be sought were methods of measuring those characteristics of a system which chiefly influenced its effectiveness, and if they synthesised as much as possible, these characteristics might come down to three. He left out the question of colour, because he presumed the object was to compare systems giving light of approximately the same colour. Thus they were left with intensity of illumination which, taken in conjunction with the particular task and its reflection factor, gave the brightness. Then there was the glare effect of the sources, and finally there was what might be called somewhat vaguely the diffusion of the light, including not only the difference between, for example, the total indirect system and the direct system, but also the direction in which the light was incident, in relation to the operator and the work. If there were reliable methods for measuring these various characteristics, then it would be necessary to set a task to a number of people and vary these three characteristics until what was considered to be the optimum combination was discovered. It would be a long job to do this even for a single task, and whether it would be possible he did not know; but he believed it was only along these lines that it was likely they would get any proper assessment of the effectiveness of a lighting system.

Mr. H. C. WESTON said he must confess that he had not, until recently, thought of the kind of experiment in which the attempt was made to determine the illumination in relation to practical high levels of performance as giving threshold values. The point had been put to him recently by Professor Bartlett, and in this sense all code illuminations must be regarded as threshold values. Dr. Stiles's paper was interesting because it showed what a difference there was between thresholds in practice and in the laboratory, and he would like to ask Dr. Stiles whether he thought the higher threshold values would remain unaltered at higher values of background brightness. The paper only dealt with one brightness.

With regard to Dr. Wright's paper, he had been wondering just what it would be possible to do with measurements of subjective brightness, if it were possible to get them. Further, the suggestion that glare might be specified in brills did not seem to be very helpful to the illuminating engineer designing an installation, because he would still have to know what conditions of brightness of source, mounting height, etc., were required in order to keep within the limits specified.

Commenting on Dr. Craik's paper, he said he presumed that the scale of visual efficiency referred to was really only another way of expressing visual acuity. Such a scale—related to different tasks—would be valuable for the purposes of vocational selection. But this would involve the measurement of visual tasks, and he felt that what was badly needed now—and perhaps before they went any farther in attempts to devise methods of assessing the goodness of lighting installations—was to see what could be done with regard to measuring tasks and classifying them on a basis of measurement.

Dr. STILES, replying on the point with regard to the difference between threshold values in the laboratory and in practice, and whether the ratio of the practical to the laboratory values would remain unaltered at higher values of background brightness, said he thought the answer was that there would be no substantial change.

The PRESIDENT asked whether the same result was obtained whether the test object was darker or brighter than the background.

DR. STILES said that laboratory threshold values for the 2 deg. test object showed little difference whether the test spot was lighter or darker than the background. More information was required on this point for test objects of different sizes viewed under different conditions.

Dr. WRIGHT, commenting on what Mr. WESTON had said with regard to specifying glare in brills, agreed that this would still leave it necessary for the designer to think in terms of brightness of

source, mounting height, etc., but at the same time he felt it would be useful to know what the glare in a particular system was. If one system was found to be so many brills, this gave some conception of the brightness, in the same way that measuring sound in phons gave an indication of relative noise. From the comparative and descriptive point of view alone he felt that to specify glare in brills would be of some use. Further, the specification of noise in phons was found to be useful, even though the sound engineers were still left with the problem of designing equipment to keep the noise below the specified limit.

Dr. CRAIK agreed with Mr. Weston that the measurement of the task was the important thing. His visual efficiency scale was mainly in terms of the acuity needed for the task. There were different ways of measuring acuity and specifying it, and it might be possible to get a numerical classification of the task which would be of some practical value.

Mr. G. H. GILES (British Optical Association) asked Mr. Craik what he understood by visual acuity. Opticians distinguished between vision and visual acuity, using the latter term as vision obtained after the refractive error had been corrected. Obviously, if the term visual acuity was not used in this sense by the lecturer his results might be substantially different, since the influence of the refractive error would not have been taken into account. The unaided vision obtained at short distance had to be related to the amount of available accommodation and consequently to the age of the patient, an important factor in the application of an instrument such as that described. In the assessment of capability to perform visual tasks the accommodative reserve was also important, particularly if the refractive error was not corrected. The amount of accommodation available showed the capacity to some extent for sustained close work.

With regard to Mrs. Macpherson's paper the device for recording blinking was most ingenious. He had noted, however, that the subjects selected were those who complained of eyestrain when engaged on a particular task. He assumed that this effect was still present after any refractive error had been corrected. If that were not done then eyestrain due to the influence of outside factors could not be, in his opinion, accurately assessed. Mrs. Macpherson had made observations on the eye movements, mainly those of looking up and looking down in its relation to the rate of blinking. Since there was in his experience a greater tendency to eyestrain with the eyes fixing at short distances in the elevated position, it might be expected that the blinking rate would alter from this cause alone and not from other causes. For close work depression assisted convergence and more comfort ensued. Might these two factors be responsible to some extent for her differences in blinking rate? One expected less blinking in the natural position of depression of the eyes with convergence and vice versa, and her experiments tended to support this view. Had the effects due to these factors been really eliminated in her experiments?

Dr. CRAIK said he was not very optimistic over visual acuity in relation to measuring glare when all other conditions were ruled out. In his case his subjects had been able to accommodate sharply on the object at the distance at which it was used, which was a full arm's length. He was interested in accommodative reserve because he had been carrying out experiments on fatigue and had been getting some rather interesting results with an accommodative test using variable fixations.

Mrs. MACPHERSON said the people on whom the experiments in her case had been carried out were Service personnel, and it was extremely difficult to say what was the cause of eyestrain. It might be partly due to small refractive errors which were not corrected. As to convergence when looking up, blinking at a great rate when looking up might be due to that. At the same time, when one did a task fairly high above the horizontal, there was a smarting feeling in the eyes which might mean that the conjunctiva were dry, possibly due to not blinking. It did not seem possible to eliminate discomfort due to looking up.

Mr. D. J. MACLEAN said he had been investigating the problem of the relation between layout of white lines on roads and ease of night driving. In this connection he was especially interested in what Dr. Wright had said with regard to the use of threshold visibility. Some experiments had been carried out at the Road Research Laboratory on varying both the space between the lines and the dimensions of each line, and the actual point at which the lines were obscured was determined. The views of a number of observers were also taken, and it was found that the results

obtained with the threshold visibility method bore no relation to the opinions expressed. From what he had heard it seemed that the most suitable method of assessing the effectiveness of lighting was ultimately to take a number of observers and get their opinions. If a sufficient number of people could be taken so that a good weighted opinion was obtained, he doubted whether any other method would be more effective.

Mr. R. MAXTED remarked that there was a danger of falling into the error of attempting to define the indefinable. There were many factors involved and there was a danger that the methods described in the papers would be regarded almost entirely in their relation to the effort to find an absolute scale of visibility. There was a possibility that, as a result, some extremely useful tools might be discarded—merely because they did not achieve quite the standard of usefulness expected. In lighting, as in medicine, there were many diverse factors in various combinations which had to be weighed by professional skill. The methods should not be set aside because they would not do the whole job.

Mr. IMRIE-SMITH said he was pleased to see that the general conclusions of the authors appeared to agree with those engaged on applying lighting and was that "it canna' be did." One of the main stumbling blocks in the assessment was summed up by the question asked by Dr. Walsh, viz.: What were we trying to assess, the whole installation or just the visibility of a particular task in a certain spot? The research work of the authors was, of course, extremely valuable in weighing different factors under a particular set of conditions.

In his paper, Dr. Wright had stated that glare was a function of subjective brightness. In studying the literature on glare one was struck by the fact that, whereas in a large number of researches brightness was quoted as a main function, in others candle power and yet others the illumination produced at the eye. There were subdivisions of the glare according to the various curves which had been produced, but it seemed to him that glare must always be a function not only of subjective brightness but also of light volume. Briefly, a study of the values and relative areas of the illumination pattern on the eye.

The chief difficulty is the provision of a suitable scale, not just the usual "visibility scale." In his view the object of the illuminating engineer was to provide an illumination that caused the minimum drain on the nervous system of the user, and it was because it implied some measure of this that the blink test had at first appeared so attractive. Now that this test had been demonstrated as untrustworthy it appeared that technique had not developed sufficiently for the desired scale of "nervous energy consumed" to be employed. Progress lay in endeavours to obtain some such nervous energy scale as a basis.

With regard to references to levels of eye adaptation, one of the speakers—he could not remember which off-hand—was reported to have stated that the level of eye adaptation was determined by the brightness within a field of only 3 degrees. This was rather a revolutionary statement and he would like the point elucidated. (*Communicated*: The statement referred to in the last paragraph is attributed both to Dr. W. D. Wright and B. H. Crawford on page 915, paragraph 1, of the American "I.E.S. Transactions" for November, 1941.)

Dr. WRIGHT replied that he agreed about glare and the volume of light. Although he had not mentioned it in his opening statement, in his paper he had referred both to subjective brightness and subjective intensity. He would like to supplement Mr. Imrie Smith's remarks on nervous energy by asking Mrs. Macpherson whether other physiological tests, such as one on the heart beat, could yield positive information.

(*Communicated.*—With regard to the relation between state of adaptation and area of adapting field, experiments had shown that the sensitivity of a given area of the retina after gazing for three minutes at an adapting field, was independent of the size of adapting field above 3 deg.* The application of the result to ordinary visual conditions, in which the eye is continually moving over the whole field of view, is obviously limited.)

Mrs. MACPHERSON said that during her experiments they had tried the pressure of one finger but not the rate of heart beat. However, as no conclusive results were obtained, the experiment was abandoned.

Dr. STILES said the point with regard to the three degrees might have arisen from a remark by Bordoni many

* Proc. Roy. Soc. B, 827, 220. 1937.

years ago, that if the source was not more than three degrees in diameter, it was immaterial what was the brightness of the area, the product of brightness and area being the determining factor. It did not mean that the whole effect on the eye was confined to an angle of three degrees.

Mr. IMRIE-SMITH said he would look up his reference and chase the matter out.

Dr. CRAIK said that Crawford's results suggested that the bright adapted area need not be more than something of that order larger than the test field.

Mr. J. S. Dow said that tests of effectiveness of lighting were apt to be based on thresholds. For example, in testing visibility in the streets there was a tendency to select objects that could *just* be seen by existing conditions and then to show that with higher illuminations an object previously unrecognisable just became visible. There seemed a need for some mode of testing which recorded the great ease with which simple operations could be performed, rather than the possibility of just being able to perform some most difficult task

Dr. WRIGHT said he suggested subjective brightness.

Dr. STILES remarked that Mr. Dow, in making his statement, had done an injustice to Taylor and Weston, because in the original work on type setting people went about in the normal way and determinations were made of the speed and accuracy of work when the illumination was at a particular level. That seemed to be the ideal way of carrying out threshold measurements. The only way to judge effectiveness must be with reference to the particular object in view. If the object was to carry out simple tasks very comfortably, then instead of taking a production rate, the worker might be asked at the end of his work whether he had had a nice day! It might be found that if the illumination was below a certain level the workers would say they had had a miserable day. Thus a threshold illumination might be arrived at above which we should have the result: comfort; below it, the result: misery.

Mr. Dow said that by such methods they judged by a certain performance, i.e., by the amount of work accomplished in a given time, or by the number of mistakes that were made. This was not quite the same thing as ascertaining how easy the operator found it to perform some simple task—so simple that the performance was almost the same over a wide range of illumination, though the degree of effort involved might be different. He admitted, however, that it was difficult to suggest a possible test on these lines—unless physiologists could devise a sure means of recording the precise amount of strain or fatigue experienced by the operator.

DR. STILES said that in the Weston and Taylor experiments the workers were not trying to work as hard as they could but just in the ordinary way.

Dr. CRAIK remarked that if the attempt were made to assess whether a man could work under conditions which, perhaps, made it a little difficult for him, it would unfortunately be necessary to continue the experiment for a long time on a large number of people because the workers might make an effort to overcome the bad conditions. It would be necessary to go on until the workers had established some sort of equilibrium as between their absolute maximum and minimum, and the very small amount of work they would do if they got "fed up," and the experiment would have to be carried on until that stage was reached.

Dr. N. H. MACKWORTH pointed out that over quite a large range of tasks it had been found paradoxically that slightly harassing working conditions tended to improve performance at first by putting the workers on their mettle. Often conditions had to be very difficult before a short test showed a fall off in performance.

The PRESIDENT, remarking that the meeting had been an extremely interesting one, said that perhaps it would be fair to say that the results had not been awfully encouraging. However, he did not agree with the speaker who said "it can't be did," and he hoped the authors would continue their work and get the right answer. Dr. Wright had asked them to be subjective brightness conscious, but he believed that many illuminating engineers were. The trouble was that they were waiting for Dr. Wright to show a method of assessing specific subjective brightness. That would be a very useful tool. Many illumination engineers had had to make suggestions of things like maximum brightness of fittings in factory lighting and the brightness of fittings in schools,

but they were perfectly conscious that they were only getting half or quarter way thereby putting so many candle-power per square inch of brightness of the fittings if they did not take into account the background brightness. Therefore, they were still waiting for Dr. Wright, Dr. Stiles, and others to tell them what to do. In addition to the various factors that could be treated, such as brightness and visual acuity, there was some nebulous factor in the background which could be summed up in the word "comfort," and he did not know how it was possible to specify that. Nevertheless, he was sure people like the authors, if they continued groping, would be able to do it some day.

Annual General Meeting

The **annual general meeting** of the Society will take place in the lecture theatre of the Institution of Mechanical Engineers (Storey's Gate, Westminster, S.W.1) at **4.30 p.m.** on Tuesday, May 11, when the report of the council and accounts for the past year will be presented and the usual formal business will be transacted.

The annual general meeting will be followed by a **Sessional Meeting** at which an address on **"Light and Vision"** will be delivered by SIR JOHN HERBERT PARSONS, C.B.E., F.R.S., F.I.E.S. (past president).

Subsequently a **Social Evening** has been arranged, and will take place, by kind invitation of the General Electric Company, Ltd., at Magnet House, Kingsway, London, W.C., at **6.30 p.m.**

A feature will be a "Brains Trust" meeting, and there will be other entertaining events. Further notice of this gathering will be given. All members who wish to be present should notify the hon. secretary in due course.

Illumination from Sources of Large Area*

A meeting of the Leeds Centre took place on March 8, 1943, at the Griffin Hotel, and was attended by about fifty members and visitors.

Mr. P. Hartill, A.M.I.E.E., F.I.E.S., read an interesting paper dealing with the problem of calculating the illumination due to large area sources such as windows, artificial laylights, etc. The author first enumerated the limitations of the Inverse Square Law when dealing with sources of large area, and went on to deal with the terms Brightness, Luminosity, and Daylight Factor. He then described the method he has developed for making a rapid calculation of the illumination at any point on the working plane due to a horizontal or vertical source of large area and known brightness. Briefly, the method is that of surrounding the point at which the illumination is to be calculated by an imaginary hemisphere and estimating, with the aid of ingenious web diagram, the area of a surface of intersection, projected on to a horizontal or vertical plane. This projected area, multiplied by the brightness of the luminous source, gives the required value of illumination at the point under consideration. The mathematical theory on which this method is based was contained in an appendix to the paper, and was not dealt with in the time available at this meeting. Mr. Hartill concluded by giving actual examples illustrating the application of his method to both horizontal and vertical sources.

Ths discussion was opened by Mr. J. R. Tolson, A.R.I.B.A., of the Leeds School of Architecture, who welcomed the opportunity of co-operating with illuminating engineers, and agreed that the paper represents a definite advance in the technique of calculating illumination values in a room or building.

Other speakers who took part in the discussion were Messrs. Holdsworth, Pogson, and Hunter, also the chairman (Dr. Whitaker) and hon. secretary (Dr. Walton). Mr. Hartill replied to all the points raised by the various speakers in a very able manner.

A vote of thanks to the author, proposed by the vice-chairman (Mr. Kelso) concluded the proceedings.

*Mr. Hartill's paper will be published in a forthcoming issue of the Transactions.

Post-war Street Lighting

Members of the Association of Public Lighting Engineers and of the Glasgow (Scottish) Centre of the Illuminating Engineering Society met in Glasgow on March 17 to discuss the present position of street lighting and make provisional plans for the period immediately after the war.

Under the chairmanship of Mr. J. H. Scott, chairman of the Scottish Centre of the I.E.S., Mr. E. J. Stewart, M.A., B.Sc., F.I.E.S., read a paper on the "Preliminary Preparations for Full Street Lighting," after which there was a very full discussion.

At the conference, which numbered nearly 150, including Bailies, Councillors, and Public Officials from places as far apart as Aberdeen and the Southern Counties, the view was expressed that while nothing should be allowed to interfere with the war effort, endeavours should be made to preserve the many thousands of pounds' worth of street lighting plant still extant. The importance of periodical inspection of fittings with reference to maintenance was emphasised. It was recommended that lantern parts should be cleaned, greased, and painted where necessary, while all removable equipment should be overhauled and stored pending its reuse.

Fresh reports indicated that some local authorities, whilst not discussing star-lighting, were preparing for speedy resumption of normal street lighting on cessation of hostilities. An early and insistant demand for street lighting could be expected.

In Glasgow alone it will be necessary to change over from A.R.P. lighting about 90,000 lamps in stairs and 28,000 in streets, in addition to relighting 4,000 lamps in stairs and over 7,000 in streets not lit since before the war, whilst in addition there are approximately twelve miles of new streets with occupied houses where no poles have yet been erected. Mr. Stewart also referred to other forms of lighting that would require restoration and renewal after the war, such as illuminated traffic signs, and to the danger that—even after all fear of hostile action has been removed—there might be a tendency to limit street lighting in the interests of fuel economy. There was also the possibility that in the future there might be some legislative control of public lighting. This had been the subject of reference at a recent meeting of the I.E.S. in London.

Living and Lighting in Post-war England

A paper on the above subject was delivered by Mr. C. A. Harding, F.R.I.B.A., to the Newcastle Centre (North Eastern Area) on March 3. In his introductory remarks Mr. Harding remarked that design should not be either for appearance or for convenience alone. The proper application of artificial light should play an integral part in the design of future buildings.

Certain standards had been adopted in the cinema and the factory, but the office and the home require fuller consideration. Provision should be made for fittings and outlets in the carcase of the building. Decisions should be taken at an early stage—delay in this respect led to ultimate trouble; likewise the insistance of reduction of installation costs to an absolute minimum.

Mr. Harding referred in encouraging terms to the future of fluorescent lighting, especially in connection with colour effects. He foresaw more definite regulation of lighting conditions in the future and the adoption of specifications which would lead to the disappearance of unsatisfactory types of fittings.

The subsequent discussion touched on a number of points in Mr. Harding's address, notably the use of the I.E.S. Code by architects, the probable trend of post-war building, the need for co-operation between lighting engineers and architects, and the combination of natural and artificial lighting.

In his reply, Mr. Harding stated that he personally made use of the I.E.S. Code in buildings designed by him. He urged the need for flexibility in domestic lighting installations. Incidentally, he pointed out that in daylight one naturally turned towards the window, whereas when artificial lighting became necessary the inclination was to turn towards the fireside.

A cordial vote of thanks to Mr. Harding terminated the meeting.

Sessional Meeting in London

A sessional meeting was held at the E.L.M.A. Lighting Service Bureau (2, Savoy-hill, London, W.C.2), at 5 p.m. on Tuesday, March 9, 1943, the President (Mr. R. O. Ackerley) presiding.

The minutes of the last meeting having been taken as read, the President called upon Mr. J. W. Howell to read his paper on "Lighting in the Cotton Industry," which was accompanied by a considerable number of lantern slides illustrating the lighting of various interiors devoted to textile work. In the subsequent discussion Mr. H. C. Weston, Mr. Alan Owen, Mr. C. W. M. Phillips, Mr. W. J. Jones, Dr. H. Buckley, Mr. J. S. Dow, and the President took part.

After Mr. Howell had briefly replied to the discussion, a vote of thanks to the author and to the E.L.M.A. Lighting Service Bureau for their hospitality terminated the proceedings.

I.E.S. Fellowship.

The following applications for Fellowship have been accepted by the Council:—

Angus, Dr. T. C.
Holmes, J. G.
James, D. C.
Marsden, J. K.
Mollan, J. H.
Stiles, Dr. W. H.

The Illuminating Engineering Society is not as a body, responsible for the opinions expressed by individual authors or speakers.

With a view to avoiding possible confusion with other publications, reference to these Transactions should be in the form :—" Trans. Illum. Eng. Soc. (London)."

Additions to List of Members.

The following applicants have been duly elected by the Council to membership in the Society, and their names have been added to the list of members:—

CORPORATE MEMBERS:—

Aldrich, E. C. .....7, Pinewood Close, Shirley, Croydon, SURREY.
Berend, P. .....".Capite," Dial Post, West Grinstead, SUSSEX.
Bidmead, F. C. .....The General Electric Co., Ltd., Moor Street, BIRMINGHAM.
Burn, L. B. .....50, Southgate Street, LEICESTER.
Byles, J. C. .....".Tweedholme," Picton Place, NEWCASTLE-ON-TYNE, 1.
Davolls, L. H. .....11, The Cleeve, Corsham, WILTS.
Fletcher, B. M. .....1, Washington Road, SHEFFIELD, 11.
Greet, L. R. .....12-15, Hill's Terrace, CARDIFF.
Henderson, R. W.....".Rockvilla," Church Lane, Sandiacre, NOTTS.
Hind, T. N. .....".Holmgarth," Westfield Drive, Riddlesden, KEIGHLEY.
James, H. L. .....35, The Drive, Longbenton, NEWCASTLE-ON-TYNE, 7.
Longden, H. .....29, Everton Road SHEFFIELD, 11.
McCully, P. .....2029th Air Depot, "Prov." A.P.O. 636. U.S. Army.
Sherwood, E. J. .....34a, High Street, Whitton, Twickenham, MIDDLESEX.
Wickes, H. J. .....17, Boldmere Drive, SUTTON-COLDFIELD.

TRANSFER FROM COUNTRY TO CORPORATE MEMBERSHIP:—

Martin, S. .....".Abbotsford," 85, Green Lane, COVENTRY.

STUDENTS:—

West, J. C. .....The British Thomson-Houston Co., Ltd., Bridal Path, Watford, HERTS.
White, A. H. .....7, Florence Road, Thorneywood, NOTTINGHAM.

THE WINDOW SCALE

A Vade-Mecum for the Fenestrator

By A. F. DUFTON, M.A., D.I.C.
(Building Research Station, Garston, Herts)
(Communicated)

The flattering reception accorded to my Daylight-factor Protractors (1) encourages me to offer a solution to the problem of estimating the area of window necessary to provide a given daylight-factor at a point, on the working plane, opposite the centre of the window.

This problem may be resolved in terms of the *daylight factor per foot width of window*, a quantity which is readily determined from a drawing.

If PA and PB are sight-lines to the top and bottom of the unobscured part of the window, and if Q and R are points on the working plane such that PAQ and PBR are right-angles, the daylight-factor-per-unit-width, opposite the centre of a narrow vertical unglazed window AB, is

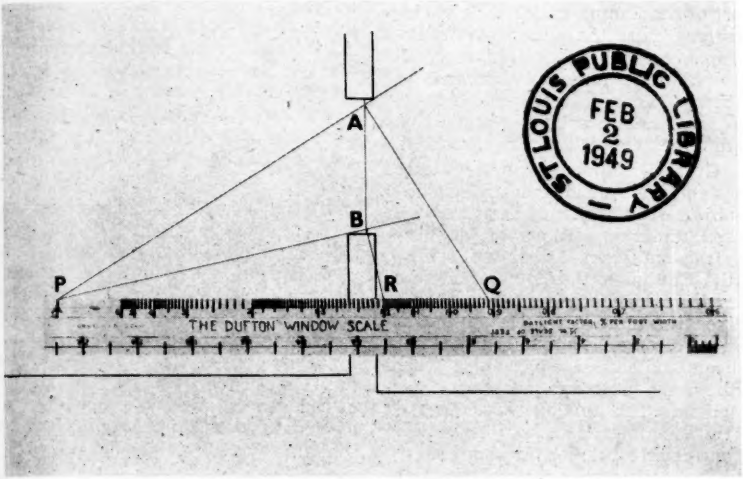
$$\frac{1}{2\pi}\left(\frac{1}{PR}-\frac{1}{PQ}\right)$$

If the window is glazed, 10 per cent. should be deducted for the loss of light on passing through the glass. The daylight-factor-per-unit-width is then

$$\frac{1}{7.0}\left(\frac{1}{PR}-\frac{1}{PQ}\right)$$

which is conveniently found from a drawing.

I have constructed a wooden scale graduated in terms of 1/7r, for use with ½-in. details. The difference between two measurements made with this scale gives the daylight-factor-per-foot-width; and from this the width of window required is obtained by simple proportion. In the figure the daylight-factor-per-foot-width is seen to be 0.29 per cent., the difference between 1.20 and 0.91; and to provide at P a daylight factor of 1 per cent. a window 3 ft. 6 in. wide would be required.



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The window scale is designed to solve quite simple problems in fenestration. Its sphere of usefulness, however, can be extended: for wide windows and for the investigation of the illumination at points off the centre-line of a window an auxiliary protractor(2) can be constructed for use in conjunction with the scale.

(1) Dufton, A. F., The Computation of Daylight Factors in Factory Design, Journ. Sci. Inst., 1940, 17 (9), 226.

(2) Ibid.

Papers Read Before Centres and Groups

HEADLAMPS, by J. H. NELSON (*Member*).

Summary of a paper read before the Birmingham Centre (Midland Area) on October 23, 1942.

Dr. J. H. Nelson, in opening his paper, said that car lighting was like any other lighting problem in that it responded to a scientific approach. It was as a branch of Illumination Engineering he wished to deal with the subject. Discussing the object of headlamps, under their various conditions of use, the author reviewed the principal controlling factors, e.g., the driver himself, other drivers, and the weather. The different methods of approach to these problems adopted by the different countries were discussed.

In Great Britain and in the United States the main driving beam had been the object of attention of designers who worked under conditions of comparative freedom from legislative control. On the Continent the point of view of other drivers and the anti-dazzle beam received the more careful attention because of strong legislation. Both driving beam and anti-dazzle beam are given by the same unit and are thus interdependent. The opinion was expressed that in spite of the lack of legislation, the anti-dazzle position in this country was more satisfactory than on the Continent, while the main driving beam was definitely superior.

A method of expressing the results of beam candle-power measurements of headlamps was described. Instead of plotting the candle-power against direction for any beam section, the square root of the candle power is plotted. This is numerically equivalent to the distance at which an illumination of 1 ft.-c. would be obtained, and it is found that curves of this type are helpful in giving an adequate picture of the beams capabilities and also in design.

The problem of fog lamps was not touched upon, but polarisation for dazzle prevention was mentioned as a future possibility.

THE PROGRESS OF LIGHTING IN INDUSTRY, by S. G. TURNER (*Fellow*).

Summary of a paper read before a meeting of the Cardiff Group (South Wales Area) on November 17, 1942.

The advent of lighting legislation in the industrial field has led to a general improvement in factory lighting. In this paper the position in regard to certain industries is reviewed and some special lighting problems are discussed.

In the heavy industries illuminations up to 3 ft.c. are becoming usual for processes of handling molten and red hot metals, formerly assumed automatically to provide sufficient illumination to work by. In steel works bays improvement is likewise welcome. In the next section of the paper the author mentioned common faults met with in lighting installations for the general engineering trades. The need for a low diversity (if possible not more than 3:1) between local and general illumination was emphasised.

Another topic discussed was the effect of the height of suspension of fittings on the available illumination. A diagram was presented to illustrate the effect of increasing mounting height. The need for some upward light in order to avoid the tunnel effect and the general design of reflector fittings were next discussed, and data on depreciation were presented.

The concluding portion of the paper was devoted to special problems. The importance of avoidance of reflected glare in the tin-plate industry was stressed and experience of the use of fluorescent tubes in this connection summarised. Special lighting problems arise in the case of buildings devoted to aircraft production and repair work. Various systems of light were discussed with the aid of sectional diagrams for roofs and the opportunities for low voltage local lighting in inspection work were illustrated. In conclusion the author remarked on the need to study quality as well as quantity of light—a point illustrated by the discussion of shadow effects in drawing offices.